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OTHER ENERGY SOURCES AND REDUCING AGENTS AS SUBSTITUTES FOR COKING COALS IN THE IRON AND STEEL INDUSTRY

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No. 392 D.7.3. OTHER ENERGY SOURCES AND REDUCING AGENTS AS SUBSTITUTES FOR COKING COALS IN THE IRON AND STEEL INDUSTRY

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INTRODUCTION:

1. Thanks to the blast furnace for the role it has played in our modern civilization; however, it does seem that we shall have to bid it farewell soon. Its basic raw material, coke is becoming short and expensive, while other sources of energy and reductants are becoming more and more abundant and getting cheaper all the time. All that remains for the blast furnace to retire is to find a process which can utilize these sources and which is technologically superior. It is the aim of this paper to help towards finding such a process. At the present, this will benefit the less developed areas which have no coking coals but have some of these other sources. In the future it will benefit the whole world.

History and future of iron making:

2. The iron and steel industry has undergone more development than any other industry in the whole history of mankind. This is understandable since iron and steel are almost as essential to man as food and air. It is no wonder then that the extent of civilization of any country can be measured by its consumption per person of these materials.

3. From time immemorial our ancestors first knew about iron when they could shape some pieces of meteorites into useful weapons. In some instances, when making their fires, they found some stones to be converted to a material resembling that of the meteorites and could also be shaped into some of their utilities. They tried to imitate these fires to produce the so called now "Sponge Iron" intentionally from that certain type of stones "Iron Ores" using a crude form of crucible. They found the process to be more efficient when they used charcoal instead of wood. They started to develop the process using their sense of engineering and it was the first furnace for iron production "The Charcoal Forge".

4. Out of these forges, furnaces of larger capacity of the shaft type were developed; but it was only when the height of the shaft was further increased that the reduced iron fused. The process was found to be more efficient when anthracite was used instead of charcoal. However, when coal was carbonized, the product (coke) was found to be the best of all. Further developments until very recently aimed at increasing the productivity of the furnace through increasing its dimensions, improving its design and construction, and blowing hot air instead of cold.

5. Coking coals were thus consumed with increasing amounts and so they are becoming less available and more expensive. Many efforts were made to postpone that day when their use in the iron and steel industry becomes uneconomic and these were

mainly by decreasing the coke consumption in the blast furnace. The ores are now prepared and concentrated before being charged in the furnace; oxygen substitutes part of the air blown into it; the furnace is operated at elevated pressure and with acid burdening ... etc. Furthermore, the coke itself is being in part substituted for in the furnace by other reductants; we know that oil or gaz injection in the furnace is a well established experience now.

6. Of course, it is only comparatively recently that petroleum and natural gas were known and thus could be used in this industry. The same applies to electric power which can already cut down more than a third of the coke consumption in iron making. What would have been the situation of the coke consumption in this industry now should these energy sources and reductants had been known a long time ago; or, in other words, what will be the relative usage of these new sources of energy and reductants with respect to that of coke in the future, and what will be the complete picture of the iron and steel industry after the advent of atomic power which is hoped to produce very cheap electricity in the not so distant future for energy and hydrogen production. If we can, in a sense, extrapolate the past we may be able to visualize the future. Iron will be produced through the gaseous reduction of its ores using electric power as the source of energy.

The position in UAR and some less developed countries:

7. There are some countries for which, having no coking coals it was difficult to establish an iron industry in their lands. The majority ofthese countries have, instead, other sources of energy and reducing agents, an example being the UAR.

8. The position in UAR: In our country we have no coking coals but we have low grade and non-coking varieties which can be gasified. We have also large amounts of waste petroleum gases and in a few years time, a tremendous amount of very cheap electric power which will be available from the High Dam and the Kattara Depression projects. For our good fortune we have iron ore reserves near the sites of these resources. There are three main iron ore bodies in the UAR; at Asswan in Upper Egypt on the River Nile, at El-Bahariya Oasis in the Western desert south of the Kattara Depression and about 200 kilometers west of the Nile, and in the Eastern desert around El-Kouseir on the Red Sea shore.

9. At the first site the High Dam is being erected and it is estimated that one kwh from this project will cost 0.5 millieme at Asswan (equivalent to 1.25 mils). This electric power can be used to produce energy and hydrogen gas for iron smelting. From energy requirements calculations (1) it is estimated that one ton iron requires about 2000 kWh. It also requires 600 cu.m. hydrogen for reduction which consumes 3000 kWh to produce. This makes a total of 5000 kWh which cost £ 2.5. From other economic studies of the project it is estimated that the fixed and running costs for the electrolytic plant per ton iron produced will be about one pound which makes the total cost of power and reductant per ton iron abour £ 3.5. This figure has to be compared with the price of one ton coke (required to produce one ton iron) in Egypt which is about £ 12.5.

10. As will be seen later, the recent trend in steel making is to use oxygen instead of air for blowing. Accordingly, with oxygen as a by-product from the electrolysis the economics of

the iron making will be even more favourable. It has been universally accepted that if the cost of one kWh is less than one fifth of that of one kilogram of coke the use of electricity will be cheaper in iron making. In our case, this will be true if the cost of one kWh is less than 2.5 milliemes which is about 5 times the estimated cost.

11. In case the iron and steel works are erected at Samalout which is the nearest town on the Nile to the Bahariya ore reserves and is about 300 kilometers south of Cairo, the cost of one kWh will rise to one millieme but the works can use both the Asswan and Bahariya ores and the electric power from the High Dam and the Kattara Depression. The cost of energy and reductant will still be lower than in the case of using coke.

12. The oilfields in Egypt are distributed on the Red Sea shore in the Eastern desert and in Sinai. The natural petroleum gas emerging from these fields together with some of that produced from the refineries is now wasted. This gas can be used both as a reductant and for producing electric power, and it has been estimated that the cost of one kWh from this source will be 2.5 milliemes. This power and the gas itself can be used for producing iron from the iron ores of the eastern desert.

13. Big reserves of low grade and non coking coals have been discovered recently in Sinai. These coals cannot be used as they are in the Iron and Steel Industry, but if gasified the produced gases can be used in the same manner as those of petroleum. Some of these coals are deep in the ground and some are near the surface. Underground gasification can be used for the former, while the latter require special gasifying reactors. The gases produced can be transferred to the site of the iron and steel works in a pipe line.

The position in some other parts of the world:

14. Although coal production in Europe was until recently sufficient for its needs, in 1958 the European Economic Organization published a report indicating that by 1965 its countries members will be short in energy resources by a quarter of their needs. Since then studies have been conducted to overcome this difficulty. At the beginning of 1962 a company was been established to build up a net work of pipe lines capable of transporting and distributing the natural gas from the Middle East to different parts in Europe up to the United Kingdom; and to a minimum capacity of ten billion cu.m. of natural gas annually.

15. Does it not stand to reason that the less developed countries of Africa and Asia should turn their attention - with the help of United Nations - to use these resources for building up their industries. Why not extend this net work to them. Huge reserves of natural gases have been discovered recently in North Africa. Similar reserves have been discovered in other parts of Africa and Asia. Why not joining all these reserves with the same and one net work to cover most of the three continents. These gases can provide both power and reductant and it will be thus possible to establish the iron and steel industry on sound and economic bases in any part of this area.

16. What has been said for the old world applies to the two continents of the new world. Every one knows about the huge quantities of natural and petroleum gases which are wasted daily in the different countries of these continents. In Venezuela for instance no less than 17 x 10 (9) cu.m. of high grade natural gas was burnt to waste in 1958; this amount corresponds to

about 22 million tons of high quality coal which can be used to produce at least 15 million tons of iron and steel. This is why we started looking into new iron producing processes which depend upon natural gas as the reducing agent. We looked into the HYL process in Mexico which is the first process to use natural gas in iron production on an industrial scale, and the H-Iron process in the U.S.A. which had just finished its semi-commercial stage.

17. Some countries have no petroleum or natural gases, but they may produce a similar product which can be used for the same purposes. Instead of coking, coals they have low grade and non-coking varieties (including lignites, brown coals, peat etc.) which are of little value, but when gasified they can be used in the iron and steel industry as mentioned above. Examples of such countries are Argentina, Malaya, Thailand, and Greece. But even in countries having coking coals, as the mines grow deeper the extraction becomes more expensive and underground gasification may be the solution to the problem.

18. When the second World War ended all countries, specially the less developed, started to industrialize. Industrialization depends mainly on the availability of cheap electric power. Burning of cheap fuels is one way of achieving this, but cheaper electricity may be produced from dams, natural water falls etc.; the High Dam being e recent example, and Niagara falls being an older one. Very recently, the Russians announced that by 1980 the electric power produced in the Soviet Union will be three times that produced in the U.S.A. now, and that half of this power will be produced by hydro-electric means. African and Asian countries are in a race to make all the benefit they can from the water power available in their lands. We have all heard about the Volta scheme in Ghana the Konakry scheme in Guinea, the Inga scheme in the Congo, and we already know about the Owen falls scheme in Uganda. In Asia similar schemes were installed in Pakistan, in India, in Turkey .... etc. In some countries most of its electricity is produced by hydro-electric means. For example, in Morocco, in Ceylon, and in Brazil about 80% of the electric power is produced by this means.

19. Many of us may have heard of that gigantic project of producing electricity from a huge dam built at the southern opening of the Red Sea. The idea is based on the fact that the rate of evaporation from the Red Sea is higher than that from the Indian Ocean. Accordingly, if the Red Sea is closed for a certain period of time the water level in it will become lower than that in the Indian Ocean and this water head can be kept constant forever according to the rate of discharge from the ocean into the sea. Such head can be used to produce hydro-electric power. If this dream is realized, all the African and Asian countries around this point will have available to them a huge amount of very cheap electricity which will help their industrialization.

20. Naturally, each country has to follow the cheapest way, consistent with its own circumstances to produce its electricity. It may be cheaper for some countries to use coal or petroleum products than to install hydro-electric power stations. But it seems that by the end of this century, or a bit later, electricity production through out the world will be either by hydro-electric means, or through the use of atomic energy. The cost of production will be much lower than it is today and consequently all power requirements will be provided through electricity; and it may be for the good luck of mankind that when natural fuels became short God provided him with better substitutes.

Electricity and reducing gases versus coke:

21. It is not only that coking coals are becoming short and their substitutes are becoming available, but these substitutes are much better than coke from all points of view and should they have been known to our ancestors coke may have never been used in the iron and steel industry.

22. The advantages can be summarized in the following:

(a) The use of electricity as a source of energy is cleaner, simpler, and easier to control than the use of other sources of energy. It can be used also for the production of hydrogen, the master of all reductants and which is a main constituents of most reductants.

(b) Hydrogen is a more powerful reducing agent than carbon or carbon monoxide; the reduction is quicker and more efficient. It does not add impurities to the metal as does coke, on the contrary it washes out any sulphur and removes a considerable part of the phosphorus. Manganese and silicon hardly enter the metal. This means that the iron produced will be practically pure, and with some ladle additions it might be possible to convert it directly to steel. In the worst case the conversion process will be less wasteful in time, effort and expenses

(c) Handling of gases is simpler than handling of solids. The gases being free of gangue material the process requires less flux and consequently less energy. The slag volume will decrease and consequently the productivity increases or lower grade ores can be used with the same power consumption and the same productive capacity. This enables the use of low grade ores which are difficult to concentrate.

(d) Sulphur being no problem the process can be acidic with all the advantages of acid smelting.

(e) When hydrogen is produced electrolytically oxygen is produced as a by-product. The recent trend in converting iron to steel is to use oxygen instead of air; the process is more efficient and the steel is of a better quality. Oxygen is prepared now intentionally for this purpose.

23. In the blast furnace the ore is charged in the lump form. However, fine ore is becoming more abundant than lump ore and it has to be agglomerated to suit the blast furnace. The sources of fine ores are numerous some ores are found in nature in the fine state, soft and friable ores have to be ground fine and re-agglomerated before being used in the blast furnace, during size preparation of the furnace charge a lot of fines is produced, Through the passing centuries much of the high grade ores was consumed and we are left with the low grade ores which are uneconomic to be used as they are in the blast furnace and have to be concentrated before being charged into it. For concentration they have to be ground fine.

24. From this, one can see that in the near future most of the ores will, for one reason or another, pass through a stage in which they will be in the fine state. It seems quite illogical to waste effort, time and money to agglomerate them just to suit the existing blast furnace process; particularly if we consider the fact that handling of fine materials using the new techniques is simpler than handling lump ores; and equally true, the rate of reduction of fine ores is much higher than that of lump ores. So,

in trying to develop a process that can use gaseous reductants and electric power instead of coke we might as well adapt it to use fine ore instead of lump ore.

Research work:

25. Research work already carried out: Due to these special circumstances of the UAR as to the shortage of coking coals and availability of other sources of energy and reductants, and because of the advantages of these other sources over coke, a research program has been set up since 1949 which aims at finding out a process that can use these sources for iron production.

26. The first work (2) was a study of the reducibility of Egyptian iron ores with hydrogen, petroleum gas, and reformed petroleum gas. The reduction was found to be very quick and most efficient with hydrogen. The petroleum gas required a special technique so that it can be used. The rate of reduction with the reformed gas was proportional to its hydrogen content. The reduction was conducted in an ordinary tube furnace arrangement.

27. In an attempt to increase the rate of reduction the catalytic effect of about one hundred compounds was studied (3). Platinum, nickel and copper compounds catalysed the reaction but only at the low temperatures where the reaction was ordinarily very slow. Above 500°C there was no effect at all. This work was considered as of no industrial value and no further attempt was done in this direction.

28. Since the rate of reaction between a solid and a gas increases with the increase in the surface area of the solid and the decrease in the diffusion path both of which can be achieved by decreasing the particle size of the solid material, the ore was reduced in the fine state. To ensure the exposure of all the particles surface to the reducing effect of the gas they were made to fall through an ascending stream of the gas in a vertical tube 8 metres high which was electrically heated. From the results of this work it was possible to establish the main features of the required process and a patent was registered at the Egyptian patent office in January 1954 (4).

29. For this process to be applied industrially the scientific and technological aspects of the process have to be thoroughly understood, and this was the aim of the research work conducted since then.

30. In the following work (5) a comprehensive study was made of the characteristics of particles and particulate systems and their behaviour when combined with a gas. The effect of temperature on the terminal falling velocity of particles in gases was formulated taking into consideration the properties of both solids and gases.

31. To study the effect on reduction of the different variables that will affect the efficiency of the process a conical silica tube was constructed so that when hydrogen is streaming upward through it at the temperature range studied its velocity will be such that the fine particles will be suspended at some position in it. The two variables that have major effect are temperature and gas/ore ratio; the rate of reduction increases by their increase and the reduction is complete in a few seconds (6). Particle and ore characteristics have a small effect which even practically vanishes at temperatures above 800°C. This result differs from what is known about the reduction of lump ores, namely, that ore and lump characteristics have a major effect on the reduction.

32. The same conclusions were arrived at when the ores were reduced in the fluidized state (7). Due to the small gas/ore ratio in this case the rate of reduction is practically directly proportional to its value. It was not possible to complete the reduction in the fluidized state at the elevated temperature used in this study. At a certain percentage of reduction which was termed the sintering point the particles stick together and fluidization stops. The sintering point was higher the lower the temperature, the bigger the particle size and the higher the gas velocity. Sintering, could be retarded by covering the particles with any of certain materials.

33. In a trial to find out how a single particle is reduced while being suspended in the reducing gas a small net of nichrome wire was made and it was possible to put small single particles in it and subject them to all the conditions of the preceding studies. The reduction propagation into the particles was studied under the microscope and the rate of reduction of a single particle could be estimated (8). By the end of this part of work it was considered that the basic studies concerning this project has been completed. However, some further studies are still essential.

34. Research work going on: A big fluidization unit made of stainless steel was constructed to study the effect of scaling up the unit and the effect of particle distribution on the rate of elutriation from the bed and the effect of self-agglomeration on decreasing this tendency. This unit will be used also in solving some of the problems that will arise during the pilot plant experimentation stage, and is particularly arranged for studying the material and heat balances in the different parts of the pilot furnace.

35. Another study concerns the effect of hydrogen on the impurities in iron ores. The results arrived at so far indicate that hydrogen removes all the sulphur if present as pyrite. It can remove a considerable part of the phosphorus especially when silica is also present.

36. Since, as will be seen later, heat has to be supplied in some parts of the furnace, and since this can be achieved by injecting oxygen at these parts, a study is being conducted to harness the reaction between oxygen and hydrogen in presence of reduced iron so that the liability of any explosion can be avoided.

37. During the work on a semi pilot model of the furnace some difficulties were encountered as to the flow of particles through the downcomers. A study has been started to overcome these difficulties.

38. The iron produced from reduction is in a sponge form and contains all the gangue material in the ore. The next and fifth phase of study concerns the smelting of this sponge iron with a flux to produce iron and slag. Different basisities were used and the iron produced was very low in manganese and silicon.

39. The next phase concerns the purification of the produced iron by oxygen blowing. No quantitative results have yet been obtained, but the removal of phosphorus was efficient.

40. Coal was recently discovered in UAR but the varieties found are non-coking and of low grade. A study is being conducted to gasify these coals to produce a gas that consists mainly of hydrogen and carbon monoxide.

41. The pilot plant stage: The work going on now is a study, using a prespex model of the furnace, of the flow pattern of solids against the upstreaming gas. A semi pilot furnace which is identical to the model, 15 cms. diameter, and consisting of many separate sections that can be bolted together, has been constructed of stainless steel. Sponge iron produced from this furnace will be smelted in a separate electric arc furnace. The productive capacity of the semi pilot furnace is about 100 kg/hr.

42. The pilot scale furnace, the equipment of which has been ordered, is 60 cms. diameter and has a productive capacity of about 2 tons/hr. The reduced iron will fall directly into the electric furnace beneath the shaft and molten iron and slag will be tapped out of the furnace. Hydrogen gas will be produced electrolytically; the electrolytic cell has been erected and tested. The gas holders are being constructed as well as the other parts of the plant.

The electrogen furnace process for iron production:

43. The principles of this proces is based upon using gaseous reductants to produce pure molten iron from fine ores using electric power as the source of energy. It is a flexible, continuous, efficient process that can use any type of grade of ore.

44. The furnace consists mainly of three parts, the top, the shaft and the hearth. The top consists of consecutive perforated trays on which the ore is dried, preheated, and partially reduced in the fluidized state. The ore descends from one tray to another through downcomers and from the lower tray into the shaft through a specially designed small fluidization unit which acts as a gas seal. The tray diameter depends upon the productive capacity of the furnace where as the number of trays depends upon the reducibility of the ore, its sintering point, and the reducing conditions inside the furnace (7). When changing from one ore to another, the only alteration will be in the fluidized bed height on the trays.

45. The partially reduced ore falls from the lower tray into the top of the shaft and by the time it reaches the hearth it will be mostly reduced. The shaft diameter depends upon the productive capacity of the furnace where as its height depends upon the ore reducibility, sintering point, and particles' characteristics (6).

46. The capacity of the electric arc furnace (the hearth) is designed according to the productive capacity of the furnace as a whole, while the energy input is designed to provide the heat requirements.

47. For the operation the ore comes to the furnace top by any means of conveying fine material, and is charged to the top tray through a star valve that prevents gas leakage. The ore is dried and preheated by exchanging heat with the waste gaz coming up. Oxygen is injected in the second tray to bring up the ore temperature to about 900°C. In the following trays the ore will be reduced by the hydrogen flowing through it. However, the extent of reduction in the bottom tray should not exceed the sintering point, and the material has to fall into the shaft before the reduction reaches this point (7). In fact, this is the most critical stage in the whole operation. If the ore falls down before the percentage reduction approaches the sintering point it will reach the hearth partially unreduced which causes a loss in production. If on the other hand the sintering point is attained fluidization

will stop and consequently the whole operation comes to standstill. Equally, if not more troublesome, problems are encountered in blast furnace operation, and, of course, in the pilot plant stage such problems will be solved and measures will be taken to allow smooth operation.

48. Suppose the sintering point of the ore used under the prevailing conditions is 85%, then the ore has to leave the bottom tray at about 80% reduction. Most of the remaining 20% oxygen has to be removed in the time the particles take to fall from the top to the bottom of the shaft. This time depends upon the terminal falling velocity of the particles and the velocity of the upstreaming gas, and accordingly can be controlled to suit the reduction characteristics of the ore (5,6).

49. Any iron oxide remaining in the ore is reduced by the hot 100% hydrogen gas entering the hearth through the tuyeres around it (2). By the addition of flux molten iron and slag are formed. The flux can be introduced by any of two ways. Either by adding it to the ore from the top, or by blowing it with the gas from the bottom; both methods will be experimented with in the pilot plant stage.

50. The gas is preheated before entering the furnace, first, by exchanging heat with the gases coming out of the furnace top, and then by electric means. It enters the hearth through the tuyeres, carrying with it extra heat from the arc furnace and goes up through the shaft and fluidized beds to achieve reduction and to convey the required heat to the system. The gas passing through the furnace is three times that theoretically required for reduction and this is to increase its reduction potential, to convey all the heat requirements to the shaft and top of the furnace, and to enable the use of bigger particles which results in a decrease in the flue dust amount and an increase in the sintering point. As it comes out of the furnace the gases pass through condensers and heat exchangers where by the formed water condenses and the cooled hydrogen is recirculated after adding the hydrogen balance to it.

The electrogen process versus other new processes of iron production:

51. The new processes of iron production can be classified into three main groups:

(a) Those that reduce lump or agglomerated ore in a shaft furnace type or in a fixed bed; examples of which are the Wiberg and the HYL processes.

(b) Those that reduce fine ore in the fluidized state as the H-Iron and Esso-Little processes.

(c) Those that reduce fine ore in a rotary kiln as the Krupp-Renn and Stratigic Udy processes.

52. The first two categories can work only on very rich or highly concentrated ores since they achieve reduction only and not smelting; the product is then charged directly in steel furnaces. However for a process to compete with the blast furnace it should be able to treat any type or grade of ore; and since the separation of the smelting operation from that of reduction costs about 200 - 400 kWh per ton of iron, the two operations must be achieved in the same and one unit if the process is to be economic.

53. The third category can treat any ore since the ore is smelted in either the kiln itself or in an attached electric furnace. But it is a well known fact that just about the worst conditions for heat and mass transfer between a gas and a solid are those existing in a rotary kiln system which means that the process is far from being efficient. This fact coupled with the complexity of the operation rules out this category as being able to replace the blast furnace.

54. From what has been said in paragraphs 3 and 4 the process of the future has to work with gaseous reductants and fine ores. Since the fluidization phenomenon gives the best heat and mass transfer between gases and solids a process based on fluidization will be very efficient. If it is possible to achieve reduction and smelting in the same unit and to use electirc power as the source of energy we will have arrived at the ideal process for our purpose, which leads to the Electrogen Furnace process.

International cooperation in this field:

55. Although the electrogen furnace process is now in the pilot plant stage it can still accept any modification or improvement that makes it more reliable. We invite, through the United Nations, all experts in this field to help us in developing this process and we particularly note those of the U.S.A. due to their long experience in this field.

56. As to our neighbours and friends in the less developed areas, which have similar circumstances as we have, we invite them to collaborate with us in developing this process, to send their representatives to take part in the research work conducted, and to be present in the pilot plant experimentation stage. Also to discuss with us and with the world experts in this field the possibility of applying this process in their countries, with whatever modifications as may be necessary to suit most their particular circumstances.

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